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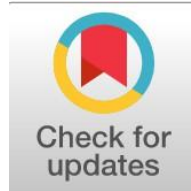
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Effect of Wiring Condenser Surface Area on the Residential Refrigerator Performance Charged with R134a and R1234yf Refrigerants Exposed to Hot Climate Ambient Temperature (Experimental Study)

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Abstract

General Background Ambient temperature variations significantly influence the thermal performance of domestic refrigeration systems operating across residential and industrial sectors. **Specific Background** Elevated outdoor temperatures impose greater thermal loads on condensers, reducing heat rejection capability and lowering overall system efficiency. **Knowledge Gap** Limited empirical research exists on evaluating alternative refrigerants and optimizing wire-and-tube condenser surface areas under diverse hot climatic conditions. **Aims** This study experimentally evaluates the performance of traditional finned, few-finned, and no-finned condensers using R134a and R1234yf refrigerants at ambient temperatures of 20, 30, and 40°C. **Results** The traditional finned condenser consistently achieved the highest coefficient of performance, while R1234yf maintained stable operating characteristics despite lower overall efficiency compared to R134a. **Novelty** The research provides a comprehensive comparative assessment of condenser surface area configurations and alternative low-global-warming-potential refrigerants under controlled hot climate conditions. **Implications** These findings offer valuable guidance for optimizing domestic refrigerator designs in high-ambient temperature regions.

Key Findings Highlights

The traditional finned condenser consistently demonstrated superior thermal performance and higher energy efficiency than few-finned and no-finned designs across all tested ambient temperatures.

Increasing the ambient temperature from 20°C to 40°C caused a reduction in cooling capacity and coefficient of performance while increasing compressor work due to higher condensing pressures.

R1234yf exhibited more stable operating characteristics under varying ambient temperatures compared to R134a, confirming its potential as an environmentally friendly alternative despite its lower overall COP.

Keywords Effect Of Ambient Temperature, Wire & Tube Condenser, Condenser Fins, R-1234yf, Condenser Performance

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Introduction

In recent years, HVAC systems, heat exchanger systems, energy-saving systems in buildings, and other systems have always been the focus of researchers. Refrigeration and air conditioning systems are important due to their use in several fields such as food preservation and providing comfort (in residential buildings, factories, cars, etc.) [1]. Reducing energy consumption is difficult with these systems, especially regarding energy savings through HVAC systems, because any improvement in them leads to covering a wide area [2]. The performance of vapor compression refrigeration and air conditioning systems decreases in very hot weather conditions with a significant increase in the energy expended, which leads to a decrease in the performance of the condensers in these systems [3]. The condenser pressure rises above the design value in very hot climates when the temperature exceeds the design value of the condenser. The condensing system in vapor compression systems can be improved by cooling the air passing through it or by increasing the surface area of the condenser exposed to the air [4]. Increasing heat loss in the condenser, changing its surface area, and reducing throttling losses in the expansion valve, which traps the refrigerant coming from the condenser and feeds it to the evaporator and without returning it to the system, is one way to improve cycle performance [5].

When choosing a specific element in the compression refrigeration cycle to improve the system's performance, this element is opposite another element inside it and is designed to work according to it, under the influence of certain external conditions and using a specific refrigerant fluid [6]. To select the condenser surface area that suits the system and improve the performance of the cycle, extremely precise calculations are done. In a test to evaluate the cooling cycle of a home refrigerator practically using an innovative evaporative condenser, it was found that there was a 45% increase in the condenser temperature for high operating conditions of air velocity, temperature and humidity, and an 88% increase in the condenser performance at low ambient operating conditions [7]. The performance coefficient improves by approximately 50%-55%, and the energy consumed decreases by 16%-32%, with practically an improvement in the thermodynamic properties when using a cooling pad between the condenser and its fan in window air-conditioners. The compression work is reduced by 58% and the performance factor is improved by 113.4% in practice by using the evaporative condenser instead of an air condenser with systems with capacities (3-300 watts) [8].

Further improvements and better coefficients of performance can be obtained for various water-cooled condensers using different arrangements in different ambient conditions, by 12.33% for water-cooled condensers, 14.43% for induced tower condensers, 18.33% for forced tower condensers, 24.41% for single cellulose pad condensers, and 29.13% for double pad condensers [9]. Energy consumption is reduced from 15% to 22% with an increase in performance (COP) from 29% to 53% by using an evaporative condenser with the wind tunnel method [10]. The spray cooling system contributes practically using a gas-liquid swirl nozzle two-phase, increasing the performance factor by 4%-8% while saving energy by 2.37%-13.53% and reducing compressor capacity in air cooling systems. It is possible to improve the cooling efficiency and reduce the amount of water loss in the cooling towers by 4.7 in coefficient of performance and 16 in energy efficiency ratio with a consumption of 844 watts/ton, and increase the energy transfer area by 3.5 times that of the water-cooled condenser for the same coil with a 50% coefficient of performance of the drain condenser compared to the air condenser for units with small capacities [11]. Latent temperature storage elements that contain paraffin, water, or a copolymer compound affect the temperature of the wire condenser. When applying phase change materials (PCM) the temperature of the condenser is reduced which leads to lower energy consumption [12]. The hot wall condenser has a capacity of 10% to 18% greater than the wire condenser of a natural convection refrigerator when the heat transfer coefficients along the length of the condenser are evaluated using simulation models of both condensers to determine the condenser capacity and pressure loss. The wire condenser design can be optimized with a 3% increase in capacity and a 6% reduction in weight for a variety of pitches and diameters of wire tubes using finite elements and a variable conduction approach [13].

Despite the long period on reports of decreased performance of refrigeration and air conditioning devices in extremely hot weather conditions, little work has been done to address the problem and it is still under research and experimentation to provide appropriate solutions [14]. There are many questions about the effect of surface areas and the application of condenser evaporation cooling in the system as well as the expected change in COP after modification in hot weather conditions. To improve the COP and save energy that can be achieved by modifying the system, an experimental investigation was conducted in this work to change the condenser surface area by controlling the number of condenser wires for a home refrigerator. Choosing the optimal arrangement and design of wire and tube condensers in home refrigeration devices requires substantial study and effort. This research aims to present the proper design of wire and tube condensers in domestic refrigerators [15].

Methodology

Experimental set up & System design

Condensers are heat exchange surfaces where thermal energy is removed from the hot refrigerant vapor. This process involves cooling the vapor to its condensation temperature, converting it into a liquid, and further sub cooling the liquid refrigerant below its saturation temperature. The compression refrigeration cycle utilizing a fluid (R134a) was studied by the test equipment for analytical purposes; this cycle was computed as the primary comparison line for the rest of the cycles. A home refrigerator operating with refrigeration fluid (R134a) was used in the current work to conduct experimental tests with a wire-tube condenser with a length of 16,500 mm, a width of 460 mm, and a height of 1,400 mm, as shown in Figs. 1 and 2. The tube-and-wire type condenser commonly used in a natural convection home refrigerator is made of iron and consists of a single tube twisted in a serpentine shape and a group of vertically spot-welded wires. To obtain a better performance coefficient for the cooling cycle in home refrigerators and the most appropriate design that leads to a better

thermal transfer area for the cycle, three condensers with fins of different numbers and distances between them were used, with details shown for each condenser, in Table 1, and Figure 3 shows the three condensers.

Special-type Bourdon gauges appropriate for a refrigeration system were used to measure the condenser and evaporator inlet pressures with an accuracy of ± 0.05 bar. Based on experimental results, pressure decreases in the condenser and evaporator were calculated to be 7% and 5%, respectively. Based on calculations, there was no discernible impact of taking these pressure drops into account on the outcomes. Using K-type thermocouples, the temperatures of the refrigerant were measured at various points in time. The positions of the cycle's pressure and temperature sensors are depicted in Fig. 2. Before measuring the temperature, the tube's surface was cleared of any dust or rust, and the thermocouple probe was then positioned on it. To reduce the thermal contact resistance between the thermocouple probe and the tube surface, thermal grease was placed at the point of contact. Insulating tape was placed around the probe to guarantee correct contact and to offset any convection effects of the surrounding air on temperature measurements.

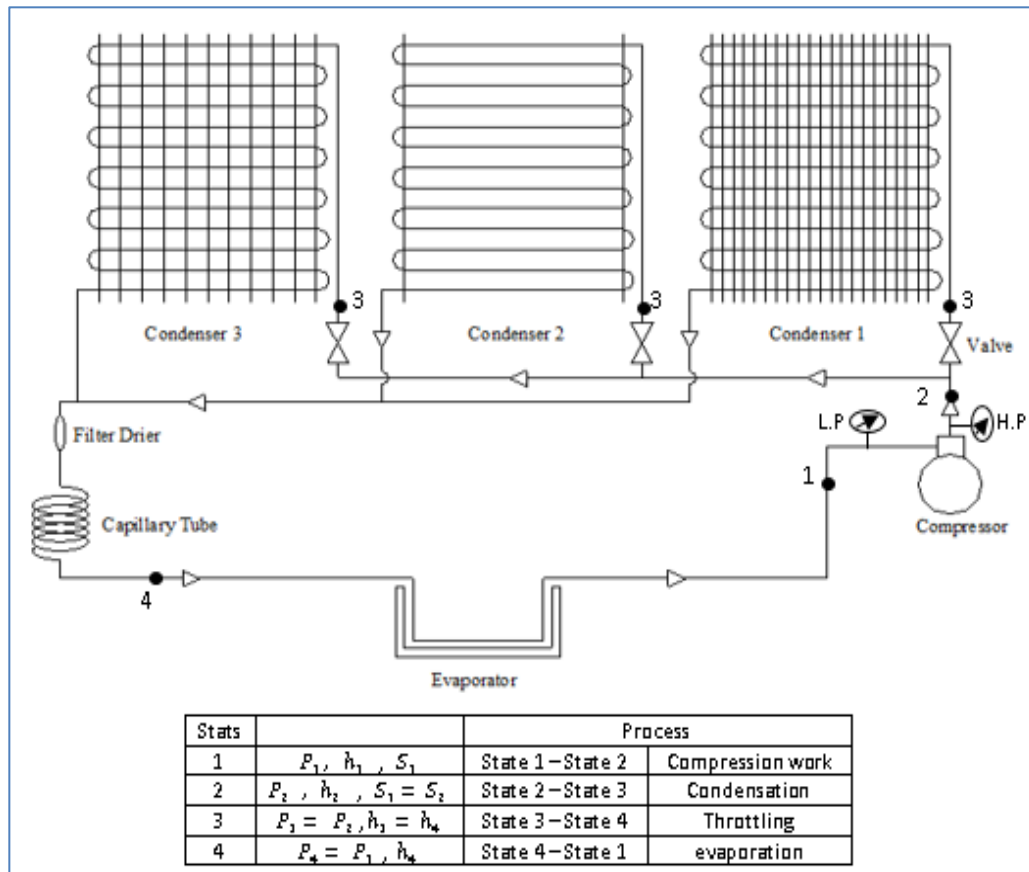


Fig. 1 Refrigeration cycle test device diagram

Table 1 Details of the Wire & tube condensers C1,C2 & C3

Description	Wire- cond. C1	Wire- cond. C2	Wire- cond. C3
Outer Diameter of tube	4.8 mm	4.8 mm	4.8 mm
Inter Diameter of tube	3.2 mm	3.2 mm	3.2 mm
No. of tube	16	20	20
Space of tube	50 mm	50 mm	50 mm
No. of wires	---	54*2	27*2
Space of Wire	---	7 mm	14 mm
Wire diameter	1.2 mm	1.2 mm	1.2 mm
Length of wire	950 mm	950 mm	950 mm

Table 2 Cases of experiments for both R134a and R1234Yf refrigerants

Experiment's Cases			
Refrigerant	Ambient temperature	surface Area Mode	Case Symbol
R134	(20°C)	Standard condenser (basic)	CaseA1T1C1
		Few fin mode condenser	CaseA1T1C2
		No fin Mode	CaseA1T1C3
	(30°C)	Standard condenser (basic)	CaseA1T2C1
		Few fin mode condenser	CaseA1T2C2
		No fin Mode	CaseA1T2C3
	(40°C)	Standard condenser (basic)	CaseA1T3C1
		Few fin mode condenser	CaseA1T3C2
		No fin Mode	CaseA1T3C3
R1234Yf	(20°C)	Standard condenser (basic)	CaseB1T1C1
		Few fin mode condenser	CaseB1T1C2
		No fin Mode	CaseB1T1C3
	(30°C)	Standard condenser (basic)	CaseB1T2C1
		Few fin mode condenser	CaseB1T2C2
		No fin Mode	CaseB1T2C3
	(40°C)	Standard condenser (basic)	CaseB1T3C1
		Few fin mode condenser	CaseB1T3C2
		No fin Mode	CaseB1T3C3



Fig. 2 Room test & Diverse test

Performance parameters calculation

To further examine the thermal performance of the refrigeration system, key parameters such as compressor operation, evaporator capacity, condenser temperature, and overall cycle performance are determined through Equations (1) - (6). Equation (1) was used to evaluate the operational characteristics of the compressor electrically by assessing voltage and current measurements. The compressor work done was calculated using (2). Equation (3) was used to calculate heat rejection to the condenser, and Equations (4) and (5) were used for calculating cooling effect and coefficient of performance for refrigeration, COP, respectively. The pressure ratio is one of the most important parameters to evaluate how efficiently a compressor works, and can be calculated by Equation (6), allowing an analytical comparison with different compression cycles. In all equations, the substates (1) to (6) refer to key points along the cycle: compressor inlet and outlet, condenser inlet and outlet, expansion valve, and evaporator exit. Digital K-type thermocouples were directly attached to the copper pipe walls at the main locations in the cycle where thermal data were needed. Four temperature measurements were taken at critical points in the cycle, both before and after the evaporator and condenser. This setup allowed for accurate observation of the heat exchange processes at play within each component. Moreover, the system incorporates pressure gauges, such as low- and high-pressure gauges. Gauges were located at two critical points in the cycle to measure pressure values. Together with temperature, these data allowed us to perform a detailed thermodynamic analysis of the refrigeration system operating under different conditions.

Table 3 Specifications of measuring devices

Device	Model/Type	Measuring Range
Low-Pressure Gauge	Refco	-30 to 500 psi
High-Pressure Gauge	Refco	0 to 800 psi
K-Type Thermocouple	K-Type Digital	-50 to 1250 °C
Thermal Reader	TM-902C	-50 to 1300 °C

$$WIC = I \times V \times P \quad \dots\dots\dots (1)$$

$$Wc = h_1 - h_4 \quad \dots\dots\dots (2)$$

$$qc = h_1 - h_4 \quad \dots\dots\dots (3)$$

$$RE = h_1 - h_4 \quad \dots\dots\dots (4)$$

$$COPR = \frac{h_1 - h_2}{h_2 - h_1} \quad \dots\dots\dots (5)$$

$$Pr = \frac{P_h}{P_L} \quad \dots\dots\dots (6)$$

Table 4 Data collection

Sym bol	Unit s	Calcula tion	Description
WIC	W	-	Electrical work energy of compressor
Wc	kJ/kg	-	Mechanical work of compressor
RE	kJ/kg	-	heat absorption from evaporator
qc	kJ/kg	-	heat rejection from the

	g		condenser
C.O.	Unit	-	Coefficient of performance Ref.
PR	less		
Pr	Unit	-	Pressure Ratio
	less		

Result and Discussion

External ambient temperature is most important for the design and performance analysis of compression refrigeration systems. As global temperatures climb especially in the Middle East and southern areas the effectiveness of alternatives to refrigerants needs to be evaluated. As part of this, they looked to compare their performance with the widely known refrigerant R134a through several practical tests [16]. To obtain a complete capture of the thermal performance, three different ambient temperatures were monitored while conducting the experiment. Such a methodology is developed to compare and determine the impact of condenser fins on refrigerator performance using R134a or 1234YF refrigerants. In the first part of the experiment, a commercial wire-tube condenser was applied under ambient temperatures of 20, 30, and 40 °C (Case A1T1C1) [16].

The system work was performed for over 80 minutes by recording a temperature reading every 10 minutes, allowing the system time to reach a steady state. The refrigerator was turned off, and the cycle was changed to use a second wire-tube condenser (Case A1T1C2) [17]. Data were acquired under identical ambient temperature conditions, and the second experimental case was performed. Afterwards, this cycle was modified by inserting a third wire-tube condenser (Case A1T1C3), and data were recorded for this case. During all the experiments, R134a and R1234YF were used as refrigerants [18]. Direct enthalpy values were not measured but estimated from the Pressure-Enthalpy (P-h) diagram of R134a and R1234yf, using temperatures taken directly in the test section and known pressures under which they occurred. The data collected included the entrance and exit temperatures for the compressor, condenser, and evaporator, as well as the high and low pressures [19]. This is shown on the P-h diagram of the cycle (Fig. 3). It should be noted that each of these experimental cases was performed once and under controlled laboratory conditions. As the ambient was aimed to be maintained as constant as possible, very small deviations due to external parameters may lead to uncertainty in measurements. The temperature sensors were calibrated before the experiments and had an accuracy of $\pm 0.5^{\circ}\text{C}$; possible biases, such as sensor calibration errors and slight variations in environmental conditions, were accounted for during data analysis [20].

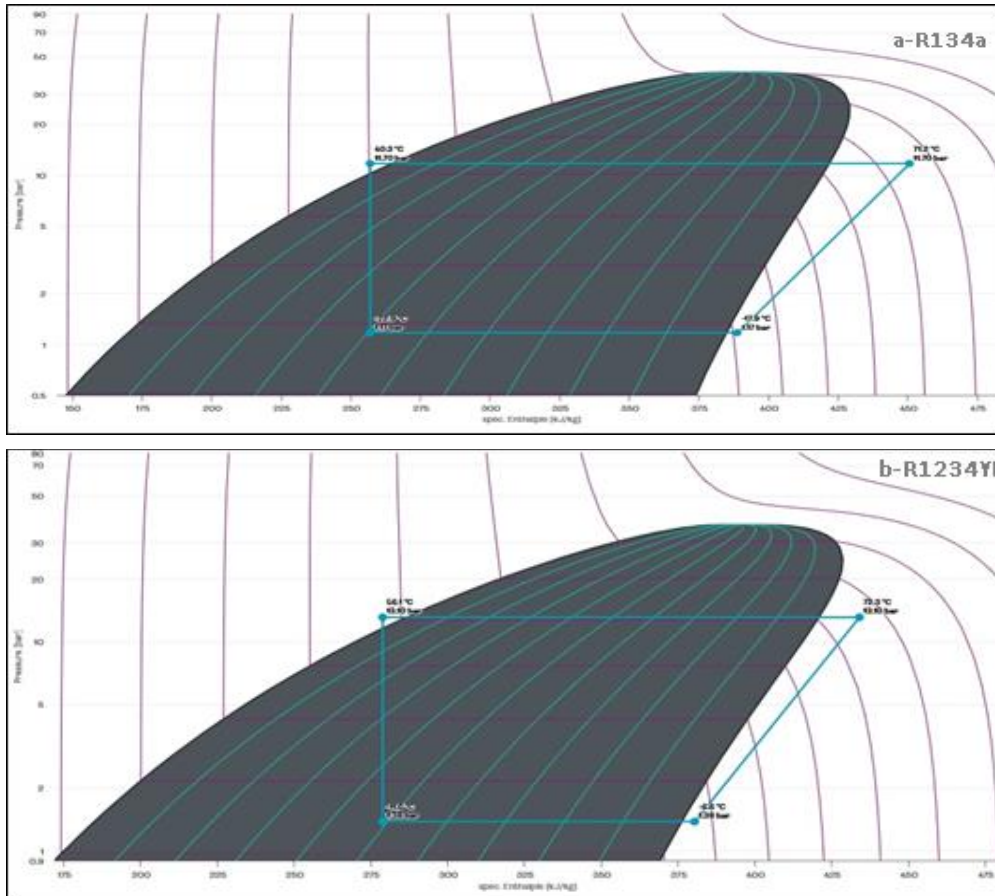
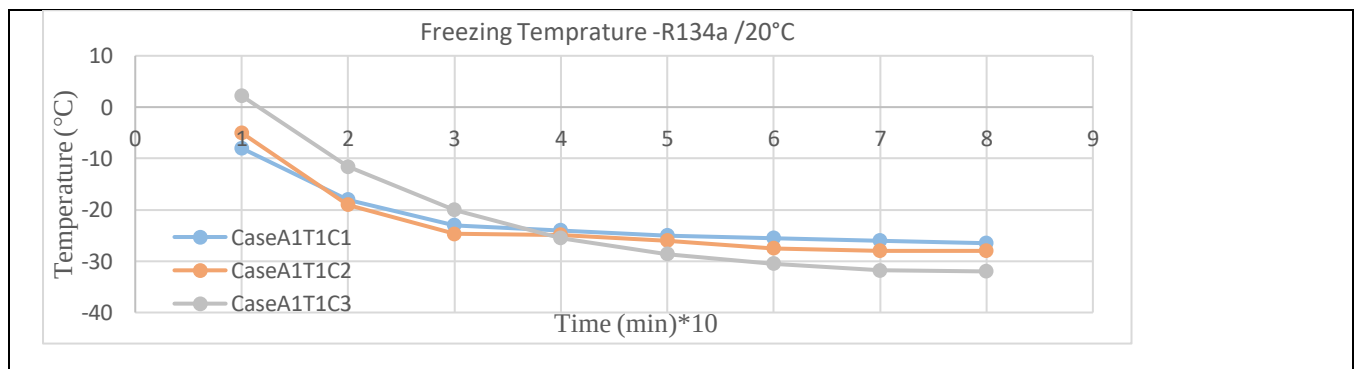


Fig. 3 The P-h diagram of Vapor compression Refrigeration Cycle (a-R134a & b-R1234yf)

The three cases are compared against a typical wire-tube condenser in terms of performance parameters. W_c is the compressor work, RE is the heat absorbed in the evaporator, and q_c is the heat rejected in the condenser. As shown in the P-h diagram, it maps all the physical parameters.

freezing and fresh food temperatures

Figure 4 shows the effect of the system's ambient temperature on the condensers. C1 is the main condenser, C2 has a few fins, and C3 is the no fins condenser, featuring no fins. The curves show that the impact of ambient temperature is most pronounced during the initial phase of the system's operation, particularly within the first 15 minutes. After this period, the system begins to stabilize. A slight delay in reaching the freezing temperature occurs at an ambient temperature of 40 °C. By the 80th minute, the temperature does not drop below -24.5 °C, unlike the lower ambient temperature of 20 °C and 30 °C for refrigerant R134a.



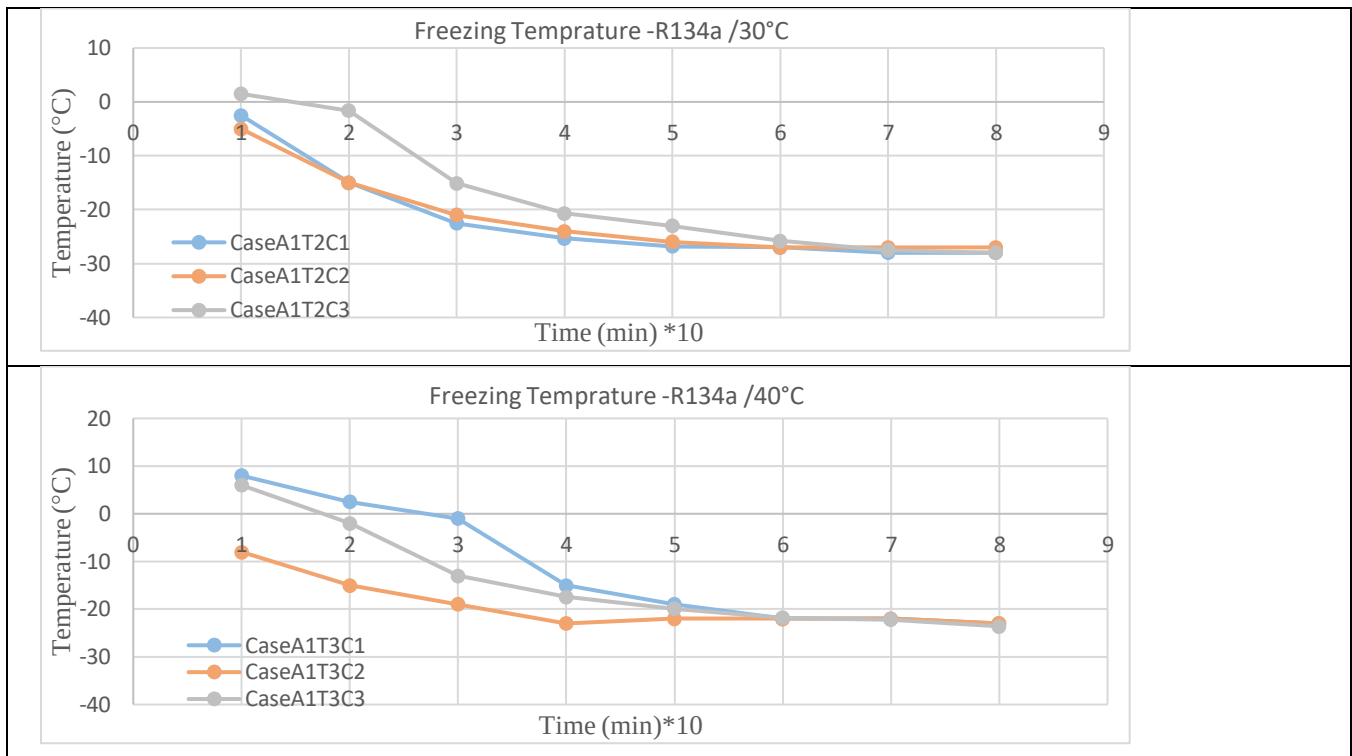
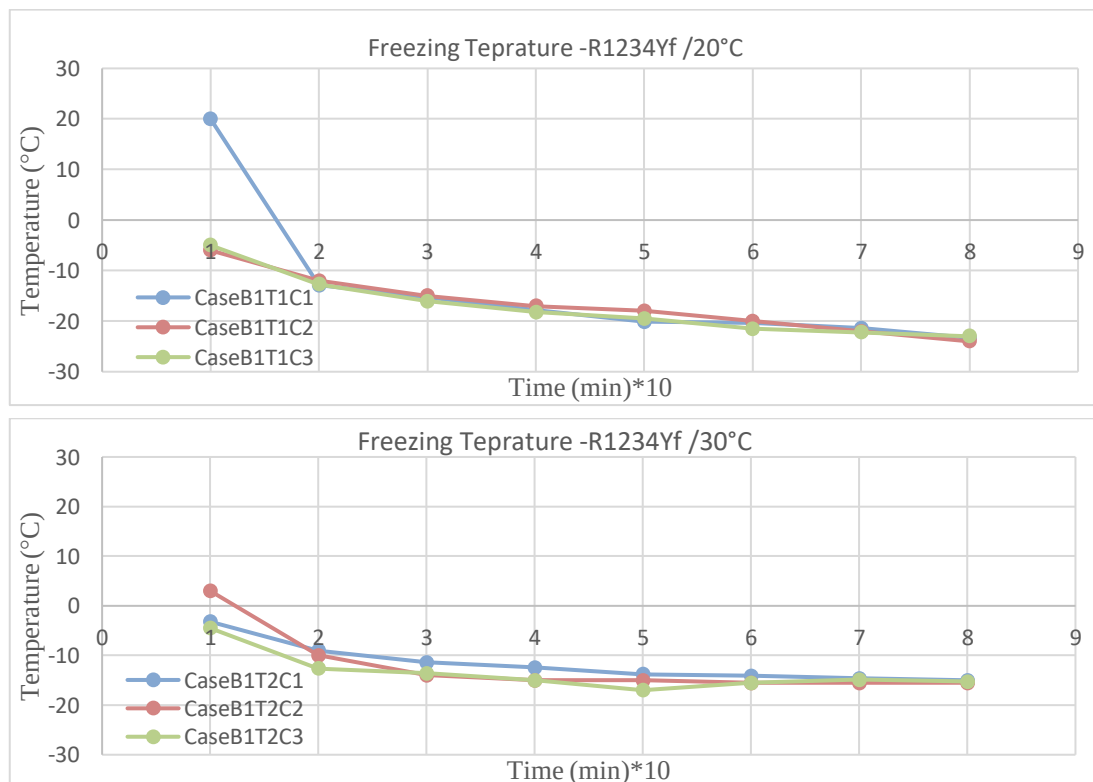


Fig. 4 Freezing Temperature with time for R134a for 3 mode of ambient temperatures

The performance of the R1234yf refrigerant, as illustrated in Fig. 5, was influenced by external ambient temperature, with optimal performance observed at 20°C. The system performance stabilized during the initial 10 minutes and continued to be regulated until reaching -25°C at the 80th minute, which corresponds to the freezing temperature value. The performance of T. ambient 30—c exhibited variability and did not achieve stability until the 60th minute. The situation deteriorated at an ambient temperature of 40°C, as the freezing temperature did not attain -10°C for all condensers.



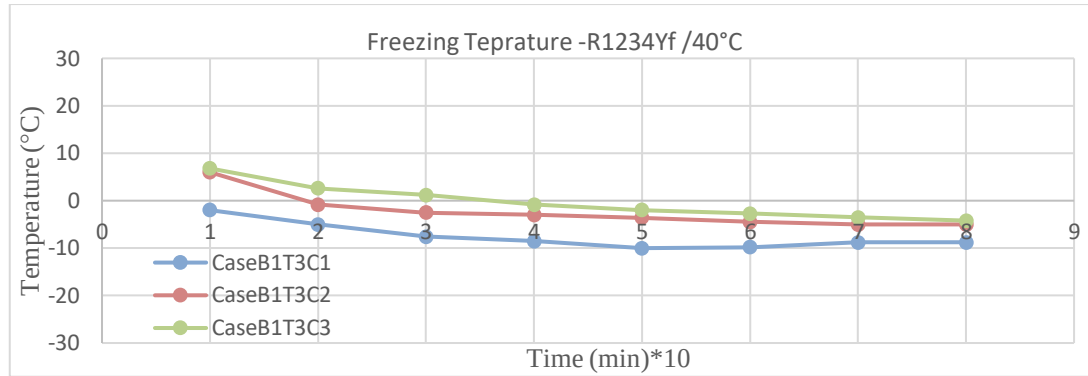
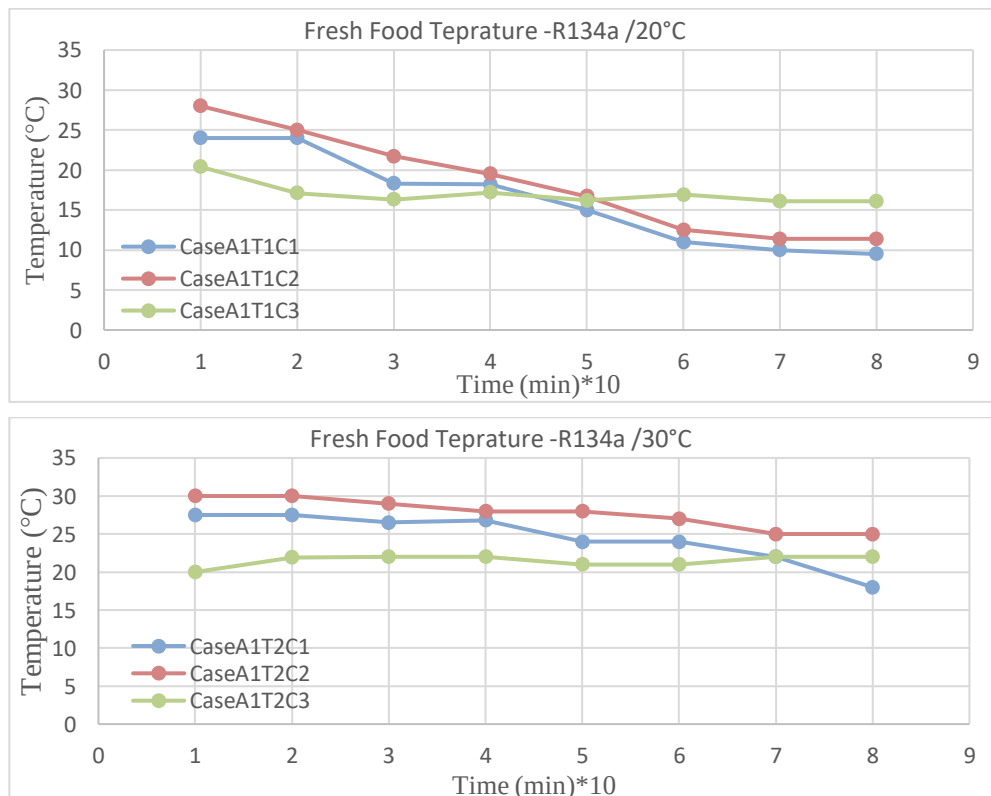


Fig. 5 Freezing Temperature with time for R1234yf for 3mode of ambient temperatures

The influence of external ambient temperature on the value of freezing temperature is evident, thus it is regarded as a significant indicator for analyzing the performance of the compression refrigeration system. Figure 6 illustrates the relationship between the fresh food temperature of the refrigerant R134a and the ambient temperature. The fresh food temperature decreased to 9°C at an ambient temperature of 20°C, while it remained above 13°C and 24 °C at ambient temperatures of 30°C and 40°C, respectively. The second evaporator in the fresh food cabinet is positioned on the suction line, where the fluid has already absorbed all the refrigerant energy from the first evaporator. This explains the observed physical behavior. Notably, during the first 30 minutes, there was a noticeable delay in the drop in fresh food temperature of fresh food, particularly in the case of, especially at ambient temperatures of 30 °C and 40 °C, and the effect was clear on the performance of the system. Refer to Figure 7 for the behavior of fluid R1234, illustrating the effects of ambient temperatures (20, 30, and 40 °C). It is evident that external atmospheric conditions have a substantial influence on temperature values. Performance was optimal at 20 °C but deteriorated somewhat at 30 °C, stabilizing after 60 to 80 minutes. The lowest temperature recorded was 16 °C and 18 °C at ambient temperatures of 30 °C and 40 °C, respectively.



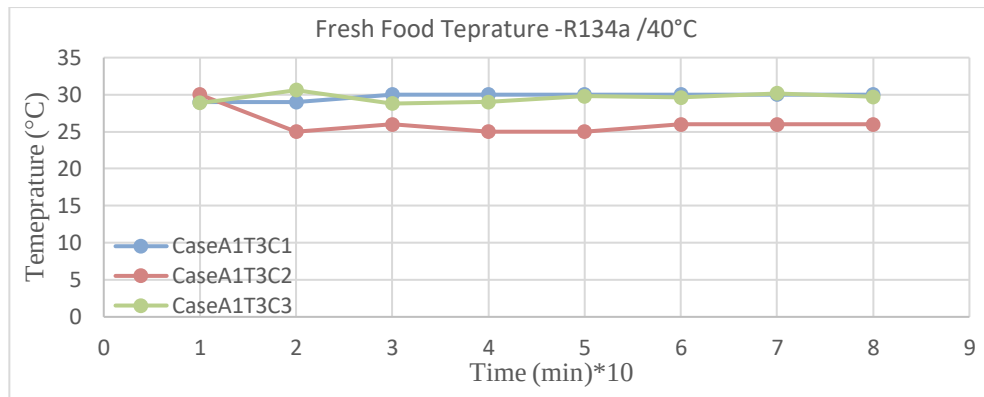


Fig. 6 Fresh Food Temperature with time for R134a for 3mode of ambient temperatures

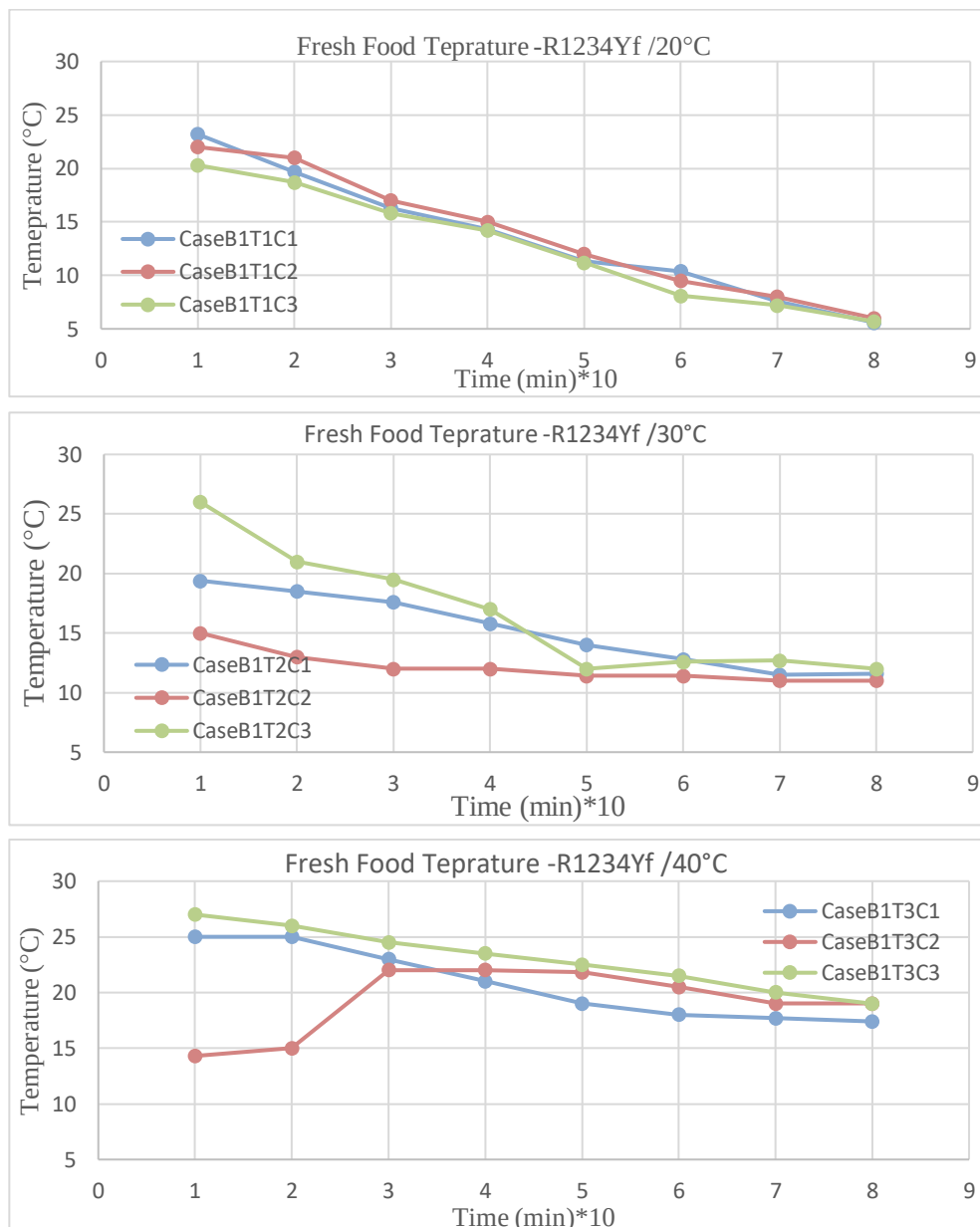
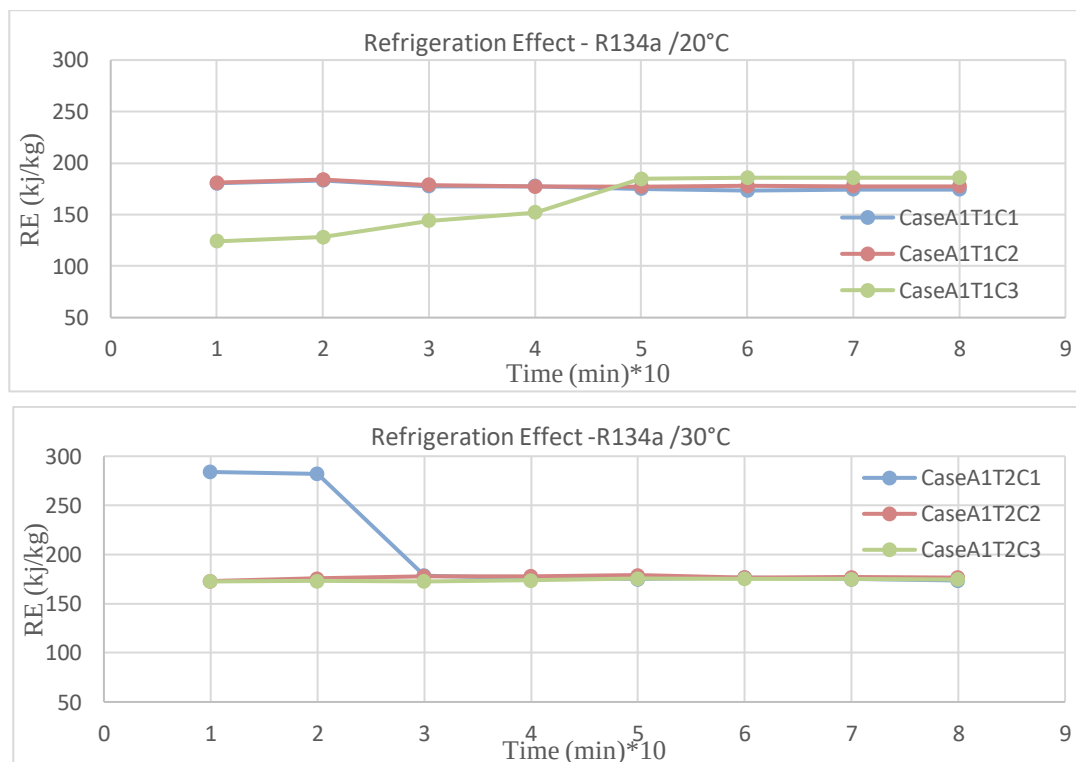


Fig. 7 Fresh Food Temperature with time for R1234yf for 3mode of ambient temperatures

Refrigeration effect and condensing duty

Figure 8 illustrates the cooling effect of the evaporator in the compression system using R134a under three external ambient temperatures (20, 30, and 40 °C) across three types of condensers. It is observed that the RE values remain stable for over 70 minutes of operation at an ambient temperature of 20 °C, with an average value of approximately 170 kJ/kg, showing no significant difference among the three condenser. At ambient temperature of 30 °C, there is a strong correlation among the three condensers, accompanied by notable stability in the RE value, particularly during the final 40 minutes. The RE values remained unaffected by variations in external air temperature, including an average value of 170 kJ/kg. However, a notable difference emerged at an ambient temperature of 40 °C, where the standard condenser demonstrated superior performance compared to the other two cases.

Figure 9 displays the RE values over the experimental duration for R1234YF across the three condensers. Upon examining the curves, a significant difference in the performance of the condensers at an external ambient temperature of 20°C is observed. The standard type condenser demonstrates superior performance compared to other condensers in T. ambient 20, 30, and 40 °C. The review indicates that R1234Yf is more influenced by variations in external ambient temperature compared to R134a, particularly during the final 15 minutes of the experiments. Figure 10 shows the heat loss in the condenser and its release to the external environment, effectively demonstrating the direct influence of ambient temperature on condenser capacity, from observe the same Figure the thermal energy expelled from the condenser remains approximately constant in magnitude, with negligible variation across the three cases. The behavior of condensers C1, C2, and C3 is consistent at ambient air temperatures of 20, 30, and 40°C. As shown in Figure 11, Refrigerant R1234 demonstrates stable numerical values and behavior, especially at outside air temperatures of 30°C and 20°C, with only slight variations at 40°C. The differences between conditions C1 and C2 are minimal, while condition C3 shows a more pronounced difference at the ambient temperature of 40°C.



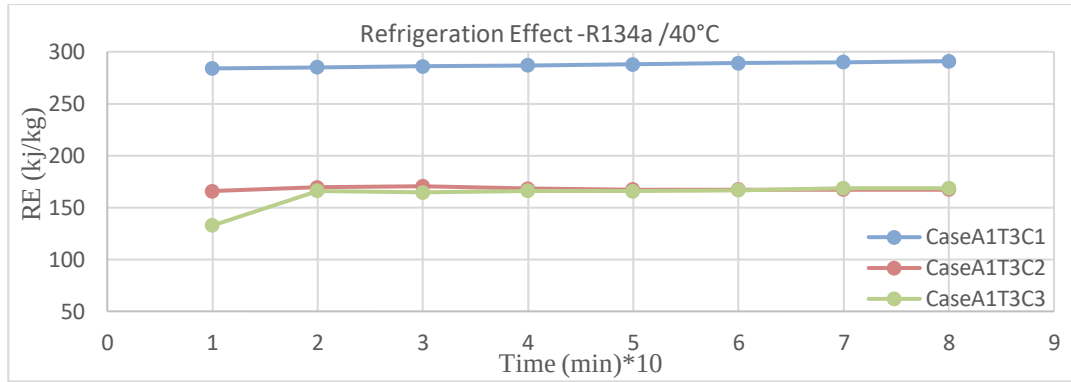


Fig. 8 Refrigeration effect (RE) with time for R134af for 3mode of ambient temperatures

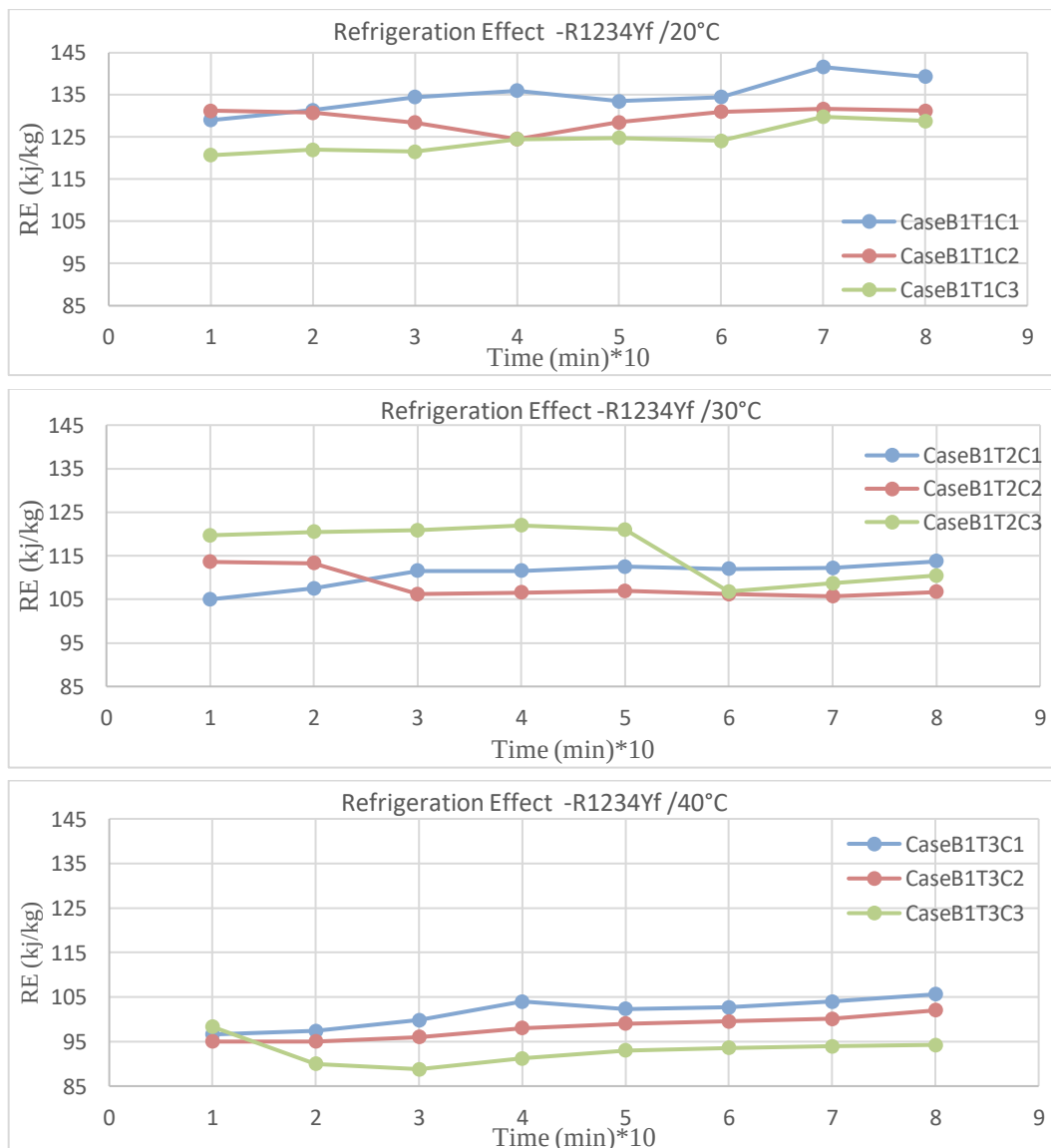


Fig. 9 Refrigeration effect (RE) with time for R1234yf for 3mode of ambient temperatures

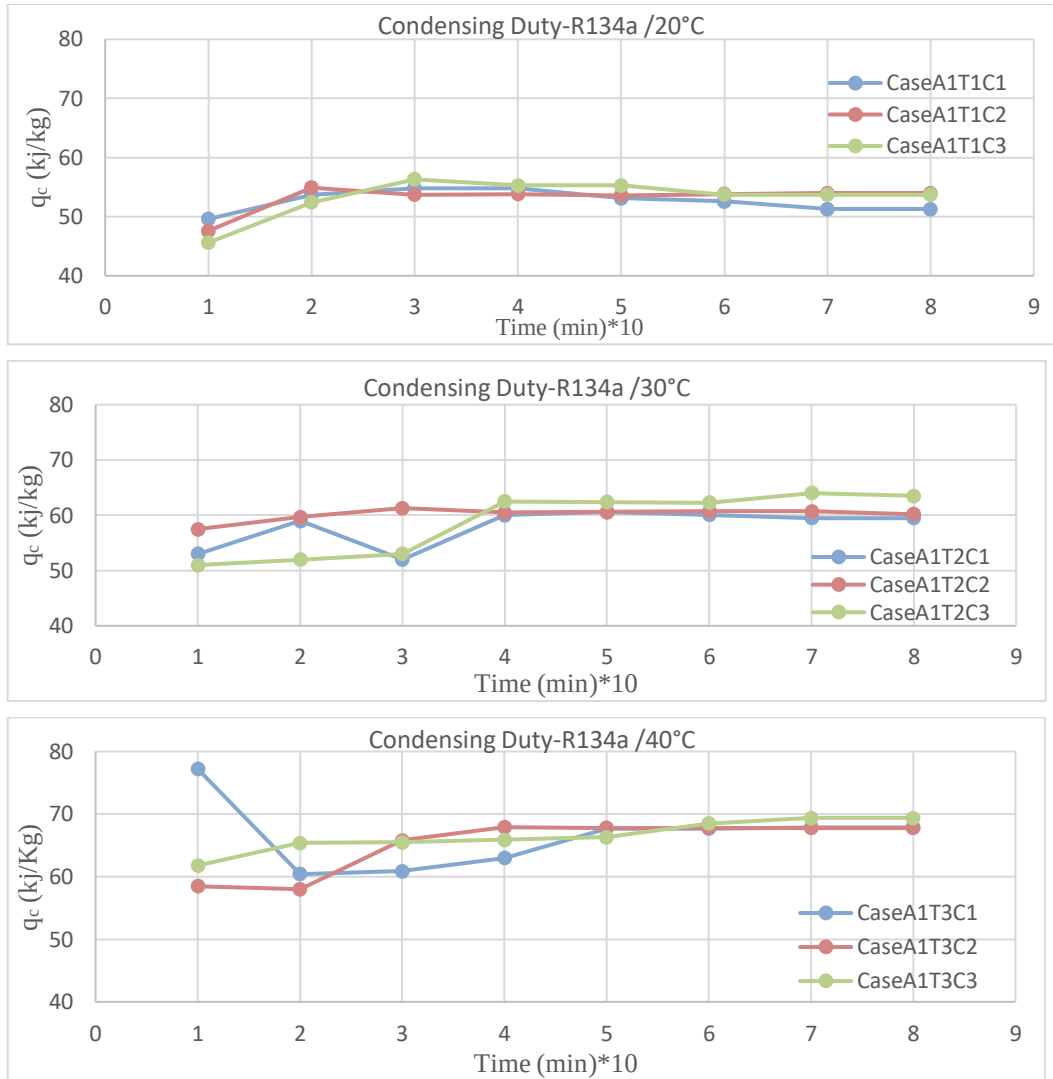
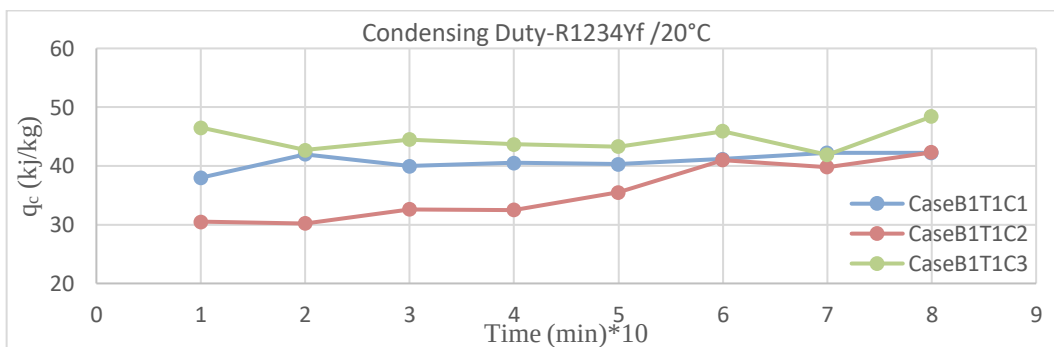


Fig. 10 Condensing Duty (q_c) with time for R134a for 3mode of ambient temperatures



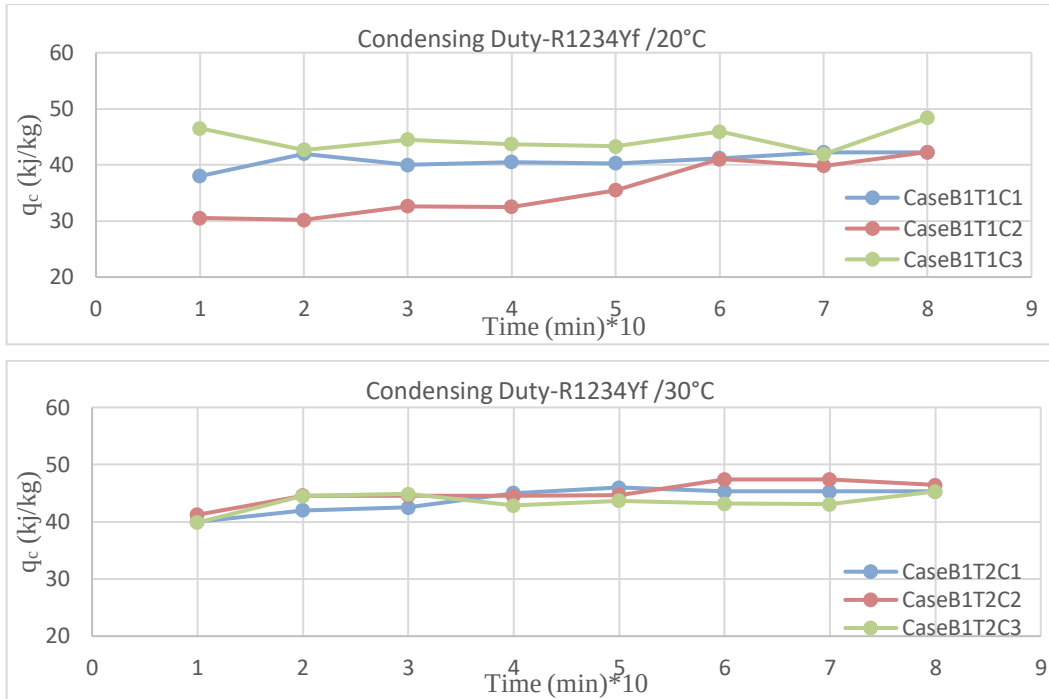


Fig. 11 Condensing Duty (q_c) with time for R1234yf for 3mode of ambient temperatures

Compressor Pressure ratio and compressor work

Fig. 12 shows the compressor work values W_c with time in the case of the refrigerant R134a and for three external ambient temperatures (20, 30, and 40 °C). By looking at the figure, you notice the stability of the compressor work values with a slight increase in the case of 30 °C T. ambient over 20 °C and a more obvious increase in the case of 40 °C. The reason is that the suction pressure increases with the rise in the external ambient temperature, so it becomes necessary to raise the pressure of the condenser to reach the condensation temperature of the refrigerant with the rise in the temperature of the fluid. Since the compression rate is constant for the compressor, the suction pressure will rise, and the high pressure in the condenser will accompany its increase. Accordingly, the compressor work rate W_c increases relatively with the rise in the external ambient temperature. Fig. 13 shows the W_c values for the fluid R1234yf, which behaves similarly to the above at T. ambient 20c °C but differs significantly at 30°C, due to the clear convergence between the three types of condensates C1, C,2, & C3 in the last ten minutes. Since the W_c values are calculated by the difference in the enthalpy values of the inlet point and the enthalpy values of the outlet point, this means that the W_c value is the amount of energy added to the fluid, which decreases relatively with the rise in the temperature of the external environment, since the enthalpy value of the fluid at the inlet point has acquired a large amount of thermal energy in the suction line and the rise in the compressor temperature with time, which makes the enthalpy value of the fluid at the inlet high. The enthalpy difference added by the compressor as a result of compression is relatively small as the temperature of the external atmosphere increases.

This explains the stability of the compression ratio Pr value shown in Fig. 14 for R134a, which stabilizes the compression ratio values during the last 40 minutes for the three types of condenser. The same behavior applies to the Pr values in the case of R1234yf, which is shown in Fig. 15, with a difference in the Pr section between R134a & R1234yf, which depends on the type of refrigerant, which is in turn affected by the rise in the temperature of the external environment. The scientific explanation for this condition is, as we mentioned earlier, that the temperature of the external environment directly affects the condensation pressure, and the higher the condenser pressure, followed by the evaporator pressure - suction - the higher it is, since the compressor's ability to raise the pressure is almost constant. This results in a constant compression ratio.

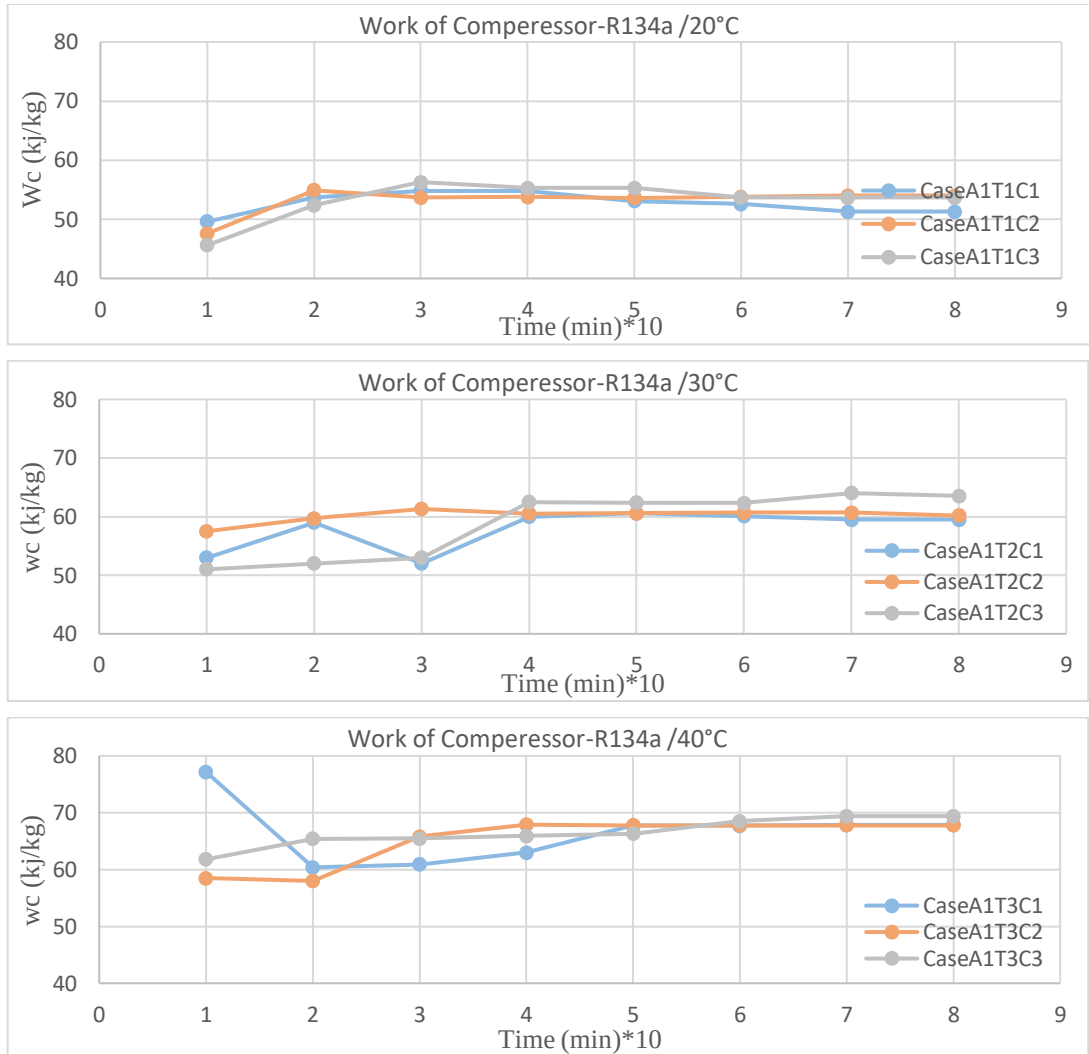
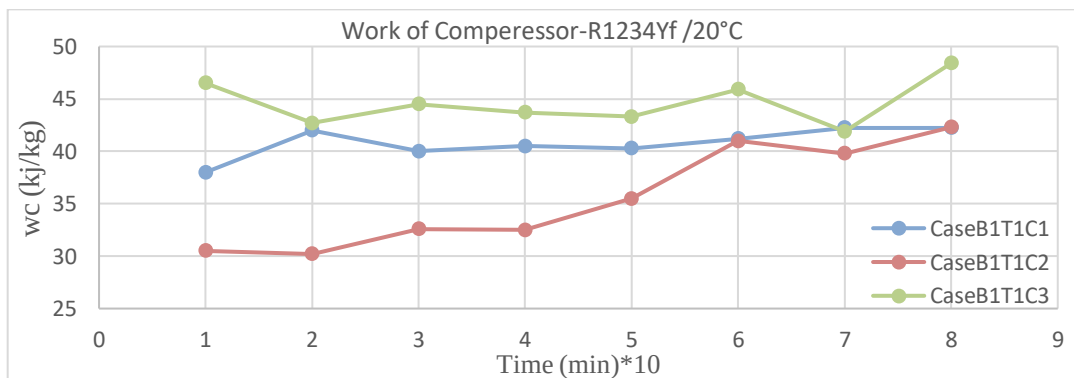


Fig. 12 Work of Compressor (wc) with time for R134a for 3mode of ambient temperatures



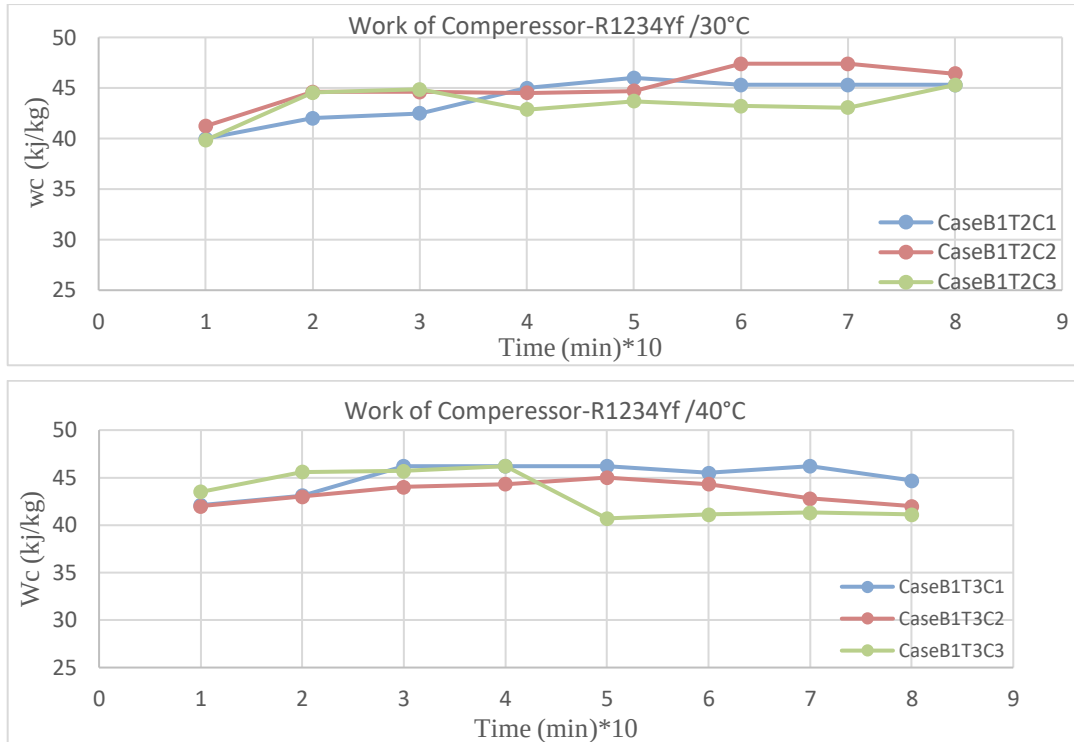
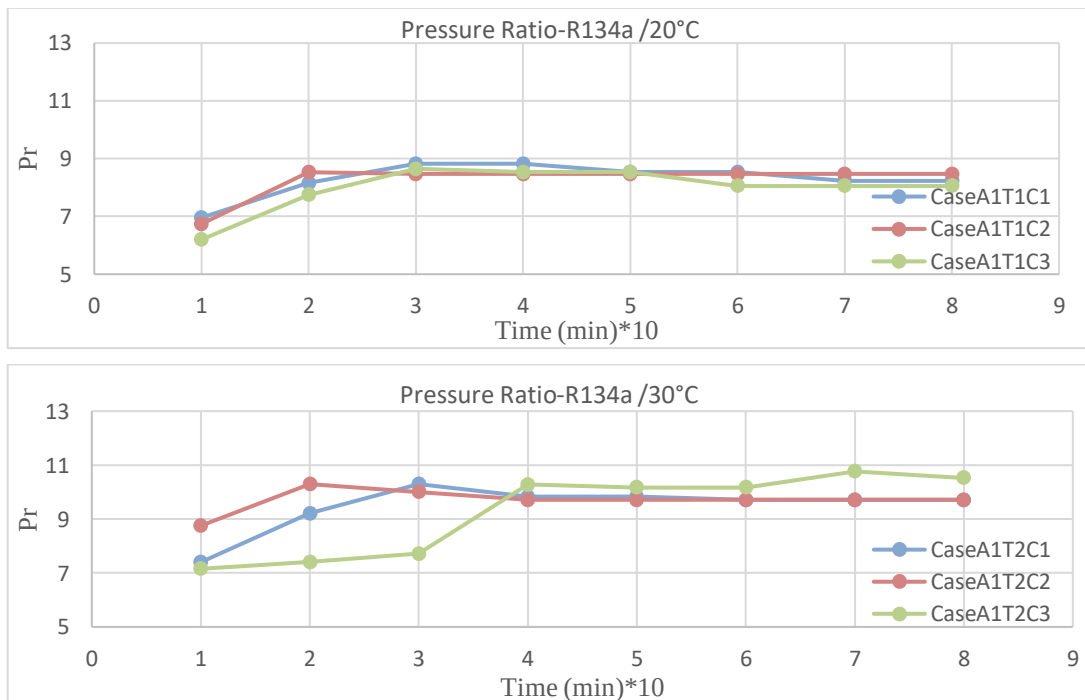


Fig. 13 **Work of Compressor (WC) with time for R1234Yf for 3mode of ambient**



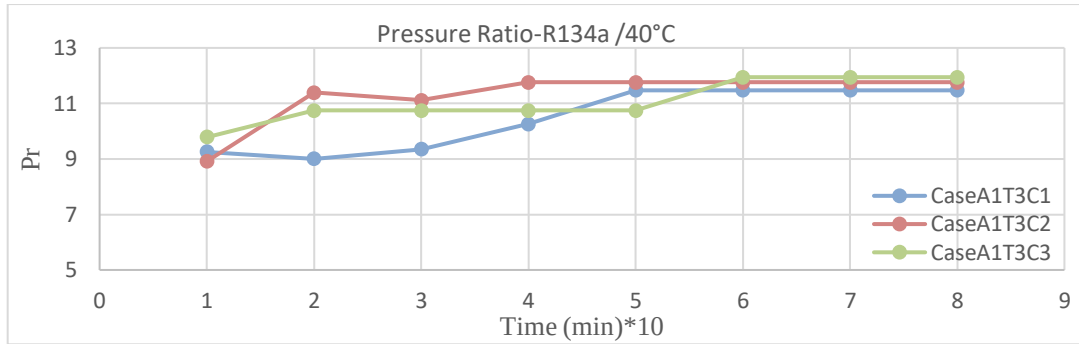


Fig. 14 Pressure ratio (Pr) with time for R134a for 3mode of ambient temperatures

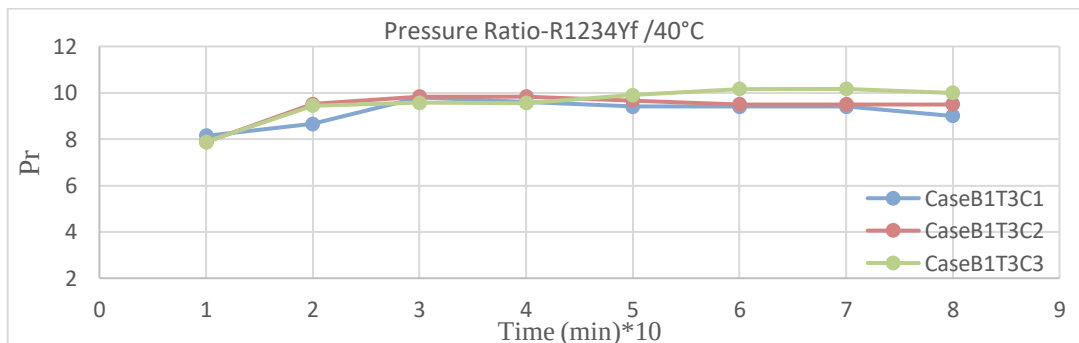
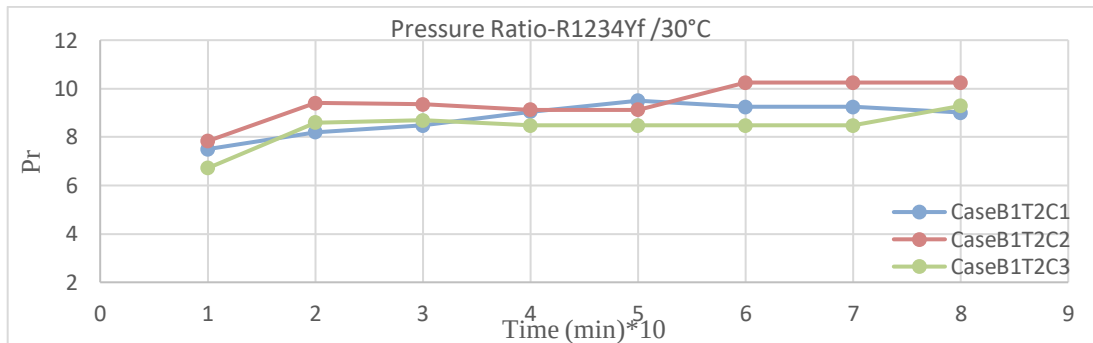
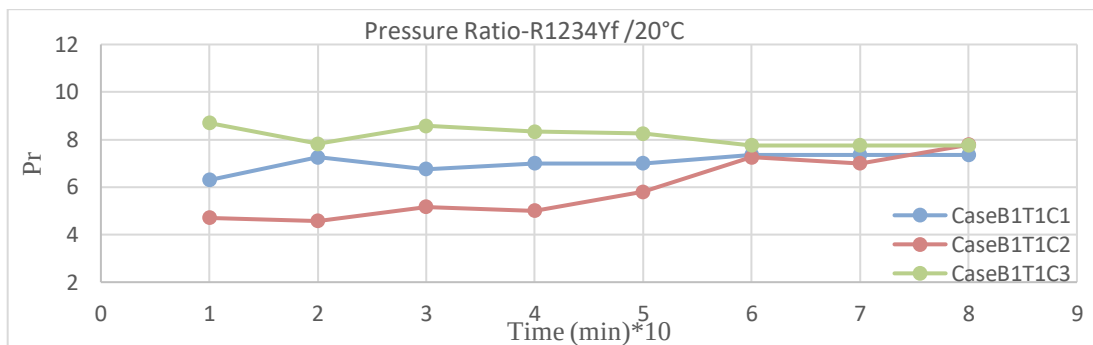


Fig. 15 Pressure ratio (Pr) with time for R1234Yf for 3mode of ambient temperatures

Coefficient of performance

Fig. 16 shows the values of the coefficient of performance (C.O.PR) of the R134a compression refrigeration system at ambient temperatures of 20, 30, and 40c for the three condensers. This figure is considered the most important among the previous figures because it takes the effect of all factors simultaneously. We can say that it takes the total summary of the effect of multiple factors on the system. From observing the figure, it is clear that the values of (C.O.PR) remain almost constant for all experiments and are more stable after minute 40 because the system reached a steady state even at the rate of the final (C.O.PR) values

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ranging between 3 and 3.4 at a 20c T. ambient and between 2.7 and 2.75 at an 30c T. ambient and between 2.4 and 2.5 at an T. ambient 40c. In general, note the superiority of the traditional condenser C1 at the external ambient temperature of 40c by maintaining the C.O.PR value at 4.2 in all conditions. This indicates the benefit of the integrated fins and the surface area affecting the performance of the system in an integrated manner with the presence of a specific percentage of heat stored in the compressor body and pipes as a result of the high external ambient temperature (40), which gives an imaginary thermal performance since this heat is acquired in the metal parts and is not real and drawn from the cooled space in the evaporator. However, the effect of the external ambient in general on the compression refrigeration system was limited.

Fig. 17 represents the thermal coefficient of performance of the compression refrigeration system for the R1234yf at ambient temperatures of 20, 30, and 40c for the three condensers C1, C2 & C3. We note from the figure that the system recorded relatively lower C.O.PR values than in the case of R134a in all cases for all condensers. This indicates the efficiency of the R134a performance compared to the R1234yf performance. However, the performance of R1234yf is more stable and consistent and was not significantly affected by the external ambient temperature. The variation in the value of (C.O.PR) was normal between 2.6-3 in all cases. This gives a good impression that R1234yf is more suitable and stable in hot climates than R134a. This fluid can be a successful alternative in high-temperature weather conditions.

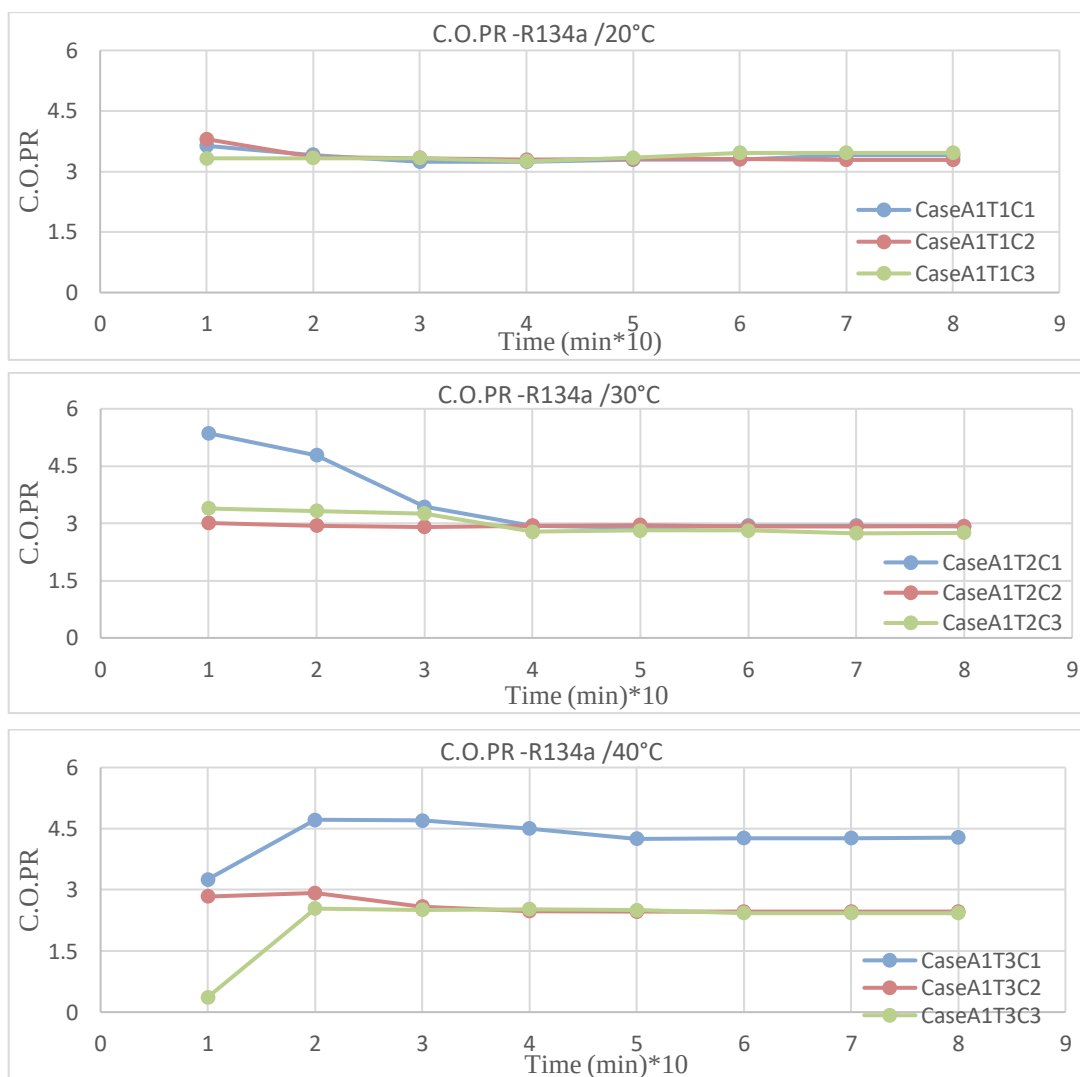


Fig. 16 Coefficient of performance (C.O.PR) with time for R134a for 3mode of ambient temperatures

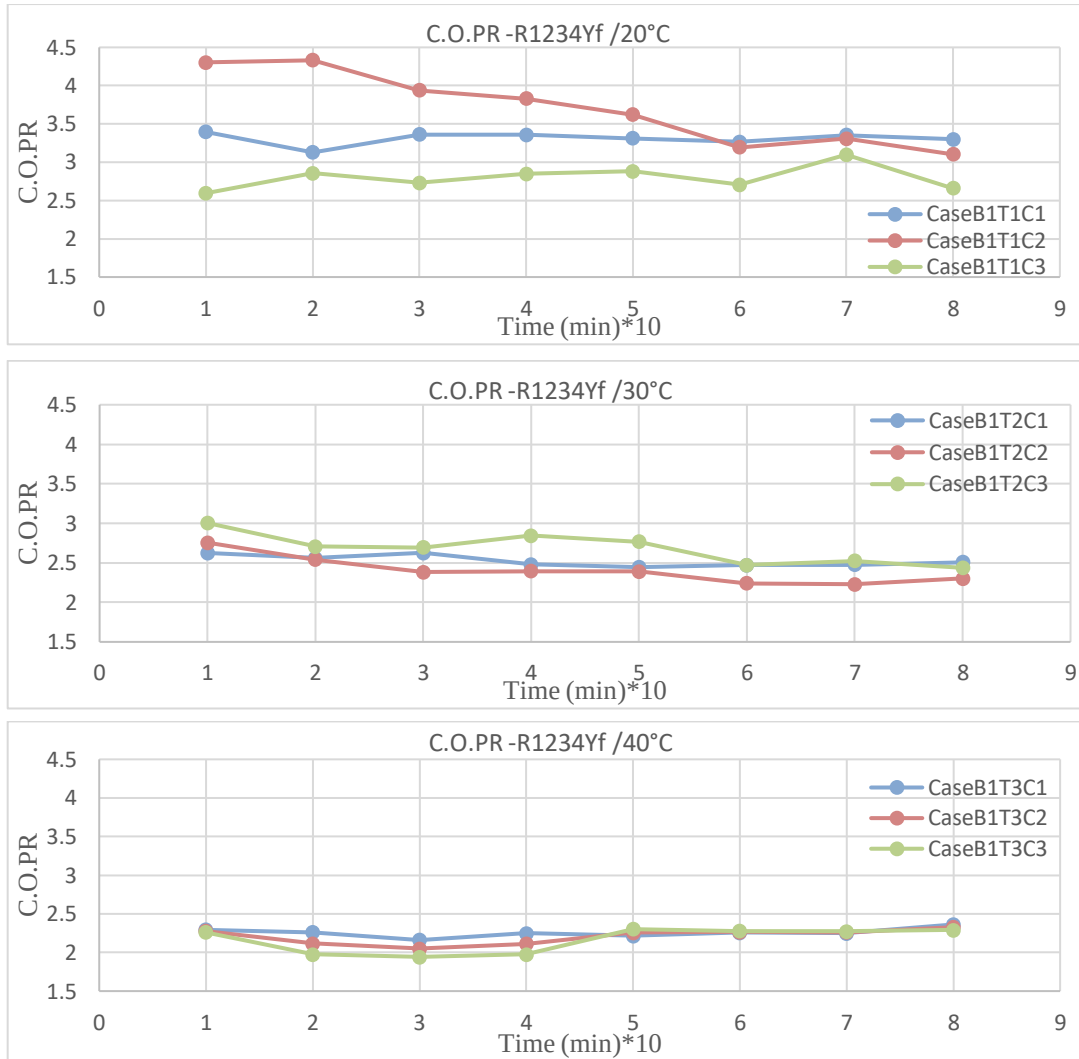


Fig. 17 Coefficient of performance (C.O.PR) with time for R1234yf for 3mode of ambient temperatures

Discussion

The experimental results demonstrate that ambient temperature has a substantial influence on the thermal performance of domestic refrigeration systems operating with both R134a and R1234yf refrigerants. As the ambient temperature increased from 20 °C to 40 °C, the refrigeration system experienced a gradual reduction in cooling capacity and coefficient of performance, accompanied by an increase in compressor work. These findings confirm that elevated outdoor temperatures impose greater thermal loads on the condenser, reducing its heat rejection capability and consequently lowering the overall system efficiency.

The comparison of the three condenser configurations indicates that condenser surface area is one of the key factors affecting refrigeration performance. The conventional wire-and-tube condenser (C1), which possesses the largest effective heat-transfer surface due to its complete fin arrangement, consistently achieved the highest coefficient of performance under all operating conditions. In contrast, the few-fin (C2) and no-fin (C3) condensers exhibited lower heat rejection rates, particularly at high ambient temperatures, highlighting the importance of adequate fin density for efficient natural convection heat transfer.

The experimental comparison between R134a and R1234yf further revealed differences in thermal behavior. Although R134a provided higher refrigeration capacity and superior COP throughout the experiments, R1234yf maintained relatively stable operating characteristics under varying ambient temperatures. Considering its significantly lower global warming potential, R1234yf remains a promising environmentally friendly alternative for domestic refrigeration applications. However, the results suggest that improvements in condenser design are necessary to compensate for its slightly lower thermal performance.

The observed increase in compressor work with rising ambient temperature is attributed to higher condensing pressures, which require greater compression energy to maintain the refrigeration cycle. Despite these changes, the pressure ratio remained relatively stable, indicating that the compressor operated within its designed performance range throughout the experiments.

Overall, the study demonstrates that optimizing condenser geometry and increasing the effective heat-transfer surface can significantly improve refrigeration system efficiency under hot climatic conditions. These findings provide useful guidance for the design of domestic refrigerators intended for regions with high ambient temperatures and support further research into advanced condenser configurations and environmentally sustainable refrigerants.

Conclusions:

This study experimentally evaluated the performance of traditional finned, few-finned, and no-finned condensers using refrigerants R134a and R1234yf under ambient temperatures of 20, 30, and 40 °C. Based on the experimental findings, the following conclusions can be drawn:

The refrigeration system achieved its best thermal performance at an ambient temperature of 20 °C for both refrigerants. As the ambient temperature increased to 40 °C, the minimum evaporator temperatures deteriorated to -24 °C for R134a and -18 °C for R1234yf, demonstrating the adverse effect of high ambient temperatures on cooling performance.

The refrigeration effect (RE) remained relatively constant at approximately 170 kJ/kg for both refrigerants across all condenser configurations. However, R1234yf exhibited greater sensitivity to changes in ambient temperature than R134a, resulting in a more noticeable reduction in system performance under warmer operating conditions.

The compressor work increased with increasing ambient temperature for both refrigerants because of the higher condensing pressure, while the pressure ratio (Pr) remained comparatively stable throughout the experimental range.

The coefficient of performance (COP_R) decreased as the ambient temperature increased. For R134a, the COP_R values were 3.40, 2.75, and 2.50 at ambient temperatures of 20, 30, and 40 °C, respectively. The traditional finned condenser consistently delivered the highest COP, reaching a maximum value of 4.20. For R1234yf, the COP_R ranged from 2.60 to 3.00, confirming that although it can serve as a low-global-warming-potential alternative refrigerant, its overall energy efficiency remained lower than that of R134a under identical operating conditions.

Among the three condenser designs investigated, the traditional finned condenser consistently demonstrated superior thermal performance, higher cooling capacity, and greater energy efficiency than the few-finned and no-finned condensers for both refrigerants across all tested ambient temperatures. These findings highlight the importance of adequate condenser surface area in maintaining refrigeration system performance, particularly under elevated ambient conditions.

Nomenclature

COPR	coefficient of performance Refrigeration
WIC	The electrical work of the compressor (W)
Wc	work of compressor (kJ/kg)
h	enthalpy (kJ/kg)
I	electric current (A)
V	electric voltage (V)
RE	refrigeration effect (kJ/kg)
Qe	cooling capacity (W)
Qc	condenser capacity (kJ/kg)
Pr	Pressure Ratio

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Figure 1.

Table 1 Details of the Wire & tube condensers C1,C2 & C3